

Bulletin 68

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

ELECTRIC SWITCHES

FOR USE IN GASEOUS MINES

BY

H. H. CLARK and R. W. CROCKER



WASHINGTON
GOVERNMENT PRINTING OFFICE
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First edition. November, 1913.

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ELECTRIC SWITCHES FOR USE IN GASEOUS MINES.

By H. H. CLARK and R. W. CROCKER.

INTRODUCTION.

The purpose of the investigation discussed in this bulletin, one of a series dealing with the use of electricity in mines, was to study the various means and methods used to confine the flashes that occur when a switch carrying electric current is opened. The flash resulting from the opening of a 250-volt direct-current circuit carrying more than half an ampere will ignite explosive mixtures of mine gas and air. An equally dangerous flash may be produced by even less current from a 500-volt circuit. Few mine electric circuits carry less than half an ampere when in use. The need of protecting the switches of such circuits in places where gas is likely to be present is therefore obvious.

Two general methods have been proposed for preventing switching flashes from igniting gas surrounding the switch. One method is to inclose the switch in a casing provided with openings that are covered with wire gauze or otherwise designed and equipped for preventing the passage of flames from the interior to the exterior of the switch casing. Switches so protected are called explosion-proof switches. The second method is to immerse the switch contacts in oil to a depth sufficient to quench any flash that may occur when the switch is operated. Switches so protected are called oil switches.

The success of the first method of protection depends upon the proper design and construction of the switch casing. It is essential to the successful operation of the second method that the switch contacts be surrounded by the proper kind of oil in good condition. There are several ways in which an oil switch may be deprived of its protective feature. The oil tank may not be filled or, if filled, the oil may leak out or be spilled. The oil tank may be removed (in some designs) and not replaced or through neglect the condition of the oil may become such that it is no longer an efficient protection. While such contingencies are not likely to occur, and although oil switches may be so designed that the loss of oil is not probable, nevertheless, as compared with oil switches, explosion-proof switches seem to

possess a greater element of safety because their protective features are inherent in their construction, and for that reason are not likely, when needed, to be missing or impaired if the mechanical construction of the switches is sufficiently durable. Moreover, switches of the explosion-proof type can be so designed that the condition of their protective features may be readily observed each time that the switches are operated.

PRELIMINARY NATURE OF THE INVESTIGATION.

The investigation described in this bulletin was preliminary in nature and was undertaken principally to obtain information upon which to base future tests of a similar character. It was not the intention of the Bureau of Mines to approve any of the switches tested. The demand in this country for switches especially designed for mine service has not in the past been sufficiently great to interest manufacturers in the development of such switches. Consequently it is not surprising that only one of the switches submitted to the bureau for test appeared to be a practical design for general mine use.

CLASSIFICATION OF SWITCHES TESTED.

Mine switches may be divided into two classes according to their use. One class of switches may be connected permanently in circuit so that there is no chance for arcs to be formed by disconnecting the leads. The other class may be used under circumstances where it is necessary constantly to remove and replace the leads. In such cases the leads are not permanently connected and arcs may be formed by removing the leads while the switch is carrying load. This fact has led to the design of a type of switch in which the leads are so interlocked with the switch contacts that the leads can not be removed or replaced while the switch is closed.

The switches submitted for test were, for the purpose of this investigation, divided into two general types according to the construction of the switch and the character of the protective features. Each type was subdivided into two classes depending upon the manner in which the switch was designed to be connected into service, as follows:

Classification of the switches tested.

Type X, protected by explosion-proof devices.

Class D, leads detachable.

Class P, leads permanently connected.

Type O, protected by submerging the contacts in oil.

Class D, leads detachable.

Class P, leads permanently connected.

Eight switches were submitted for test. The table following shows the number and classification of the switches and gives a symbol by which each switch is designated in this report:

Number and designation of switches tested.

Number of switches submitted.	Type.	Class.	Designation symbol.
1	X	D	XD1
1	X	P	XP1
2	O	D	OD1 and OD2
4	O	P	OP1, OP2, OP3, and OP4

GENERAL CHARACTER OF TESTS.

The tests were originally intended to cover only type X switches which, in any size and capacity, could be tested without enlarging the generating equipment of the bureau. It seemed to be a foregone conclusion that type O switches would not ignite gas if the oil tank of the switch were properly filled with the proper kind of oil, unless the switches were opened under short-circuit conditions while connected directly across the terminals of a much larger generator^a than was at the disposal of the bureau. Such a condition as last mentioned does not usually exist in the gaseous parts of coal mines and therefore oil switches would not have been included in this investigation had it not been that most manufacturers had nothing else to offer and earnestly requested that tests of oil switches be made. The available facilities of the bureau limited the capacity of the switches examined to 100 amperes and 225 volts.

METHOD OF TESTING TYPE X SWITCHES.

Type X switches were tested by operating them under load while the switch casings were filled and surrounded by explosive mixtures of gas and air. The flash caused by the operation of the switch invariably ignited the gaseous mixture contained within the switch casing, and the protective devices with which the switches were equipped were supposed to extinguish the resultant flames before they could issue from the casing of the switch and ignite the gas surrounding it.

METHOD OF TESTING TYPE O SWITCHES.

Type O switches were tested by operating them under load while the switch casings were filled and surrounded by explosive mixtures of gas and air. No ignition of gas took place as long as oil covered the switch contacts to the depth specified by the manufacturers.

^a The capacity of the generator used in the tests was 200 kw. at 225 volts.

The facts determined by the test were therefore the extent to which the oil level of the various switches could be reduced by operation under load. The tendency of the oil to evaporate was determined by placing the switches in an inclosure where comparatively high temperatures were maintained for several weeks.

KIND OF GAS USED.

The natural gas supplied to the city of Pittsburgh was used in all tests. Its average composition at the time of the tests was approximately as follows: 83.1 per cent methane or marsh gas, 16.0 per cent ethane, 0.9 per cent nitrogen, and a trace of carbon dioxide. The term "gas" wherever used in this report refers to this natural gas. The most explosive mixture of such gas and air was determined to be one combined in the proportion of 8.6: 91.4.^a

TESTING EQUIPMENT.

The equipment used in the tests included the following:

A gas-tight gallery or inclosure in which the switches were tested. This gallery was provided with a fan and accessory piping.

A device for determining the percentage of gas in the mixture.

A pressure indicator attached to the casings of type X switches to record the pressure developed therein by the explosion.

A rheostat for loading the switches with the proper current.

A system of piping and valves connecting the casings of type X switches with the fan intake for the purpose of filling the switch casings with the gaseous mixture that surrounded them.

Mechanisms for automatically operating the oil switches.

A small house in which the switches were mounted for the evaporation test.

TESTING GALLERY.

The gallery in which the switches were tested was a boiler-plate cylinder, 10 feet in diameter and 30 feet long, set horizontally upon a concrete foundation. Seven feet from each end the cylinder was stopped off with diaphragms of heavy manila paper reinforced with cheesecloth and painted with one coat of white lead and oil to make them gas tight. A manhole cut in the side of the gallery between the diaphragms made entrance possible without disturbing the paper stoppings. An exhaust fan, driven by an electric motor, was connected to the gallery from the outside for mixing and circulating the gas and air. The capacity of the fan, as connected, was about 1,000 cubic feet a minute. The gas-feed connection was made through a gas meter to the fan intake.

^a Tests by G. A. Burrell, chemist, Bureau of Mines.

GAS-PERCENTAGE INDICATOR.

A special instrument was developed to indicate directly the percentage of gas in the testing mixture. This instrument, which is described in detail in Bureau of Mines Bulletin 46,^a showed, without delay, when the gaseous mixture passing through the fan contained the proper percentage of gas, and was especially helpful in determining whether or not the casings of type X switches had become filled with the gaseous mixture.

RECORDING PRESSURE INDICATOR.

An indicator of the type used in taking cards on gas engines was connected to the casings of the type X switches. The spring of the indicator was wound by turning the drum and was held in tension by a ratchet, which was released by an electromagnet at the same time that the igniting spark was applied. By this arrangement a curve was obtained that resembled half of an indicator diagram taken on an engine.

LOADING RHEOSTAT.

The loading rheostat consisted of cast-iron grids connected to a suitable controller, which was provided with means for automatic operation if desired.

GAS PIPES AND VALVES.

The casings of type X switches were connected to the intake of the fan by 1½-inch pipe provided with quick-acting valves that were held closed by a spring and opened by pulling a cord which was attached to the valve handle and was led to a point outside the gallery. Just before igniting the explosive mixture within the switch casing the observer closed these valves so that the only opening in the casings was through the protective devices.

MECHANISM FOR OPERATING THE OIL SWITCHES.

The mechanism for operating the oil switches consisted of a small, entirely inclosed motor, connected by gears to a system of levers that operated the nonautomatic type O switches in much the same way that they would be normally operated by hand. The number of operations was recorded automatically by a revolution counter attached to the operating mechanism.

The same mechanism, in connection with a cylinder and piston operated by air pressure, was used to connect the automatic type O switch to the power supply and to reset the switch after the rush of current had caused it to operate.

^a Clark, H. H., An investigation of explosion-proof motors: Bull. 46, Bureau of Mines, 1913, p. 12.

EVAPORATION HOUSE.

The tests to determine the effect of evaporation upon the oil level of type O switches were conducted in a small house provided with electric heaters. The house was about 5 feet wide, 5 feet 6 inches long, and 7 feet 6 inches high inside. The air in this house was completely changed about three times an hour by natural ventilation.

SWITCH XD1.

DESCRIPTION.

Switch XD1 was a 200-ampere, 250-volt, double-pole, single-throw, slow-break, knife-switch, mounted in a cast-iron casing com-

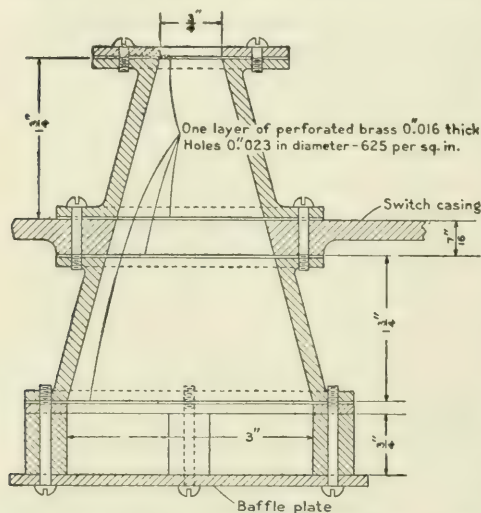
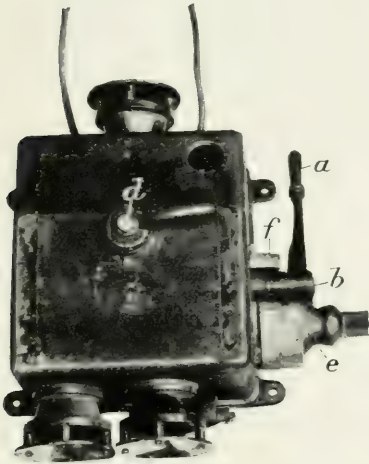


FIGURE 1.—Sectional view of switch XD1 protective devices.

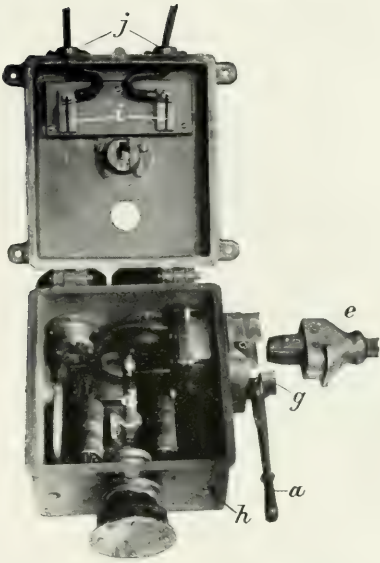
posed of two parts hinged together. The details of construction are shown in Plate I, *A* and *B*. The switch blades consisted of National Electric Code enclosed fuses mounted on a swinging yoke. The switch was operated by a handle, *a*, pinned to a stud, *b*, that passed through the casing and constituted one of the pivots of the swinging yoke (Pl. I, *A*). Leads from the source of current entered the casing through gas-tight bushings, *j*, and were connected to the terminals, *i*

(Pl. I, *B*). The connection to the load was made by inserting an attachment plug, *e*, into the receptacle, *c* (Pl. I, *B*). In order to prevent the improper operation of the switch, the switch blades, the attachment plug, and the two parts of the casing were interlocked so that it was impossible to manipulate the switch when the casing was open, to open the casing when the switch was closed, to close the switch before the attachment plug was in position, or to remove the attachment plug when the switch was closed.

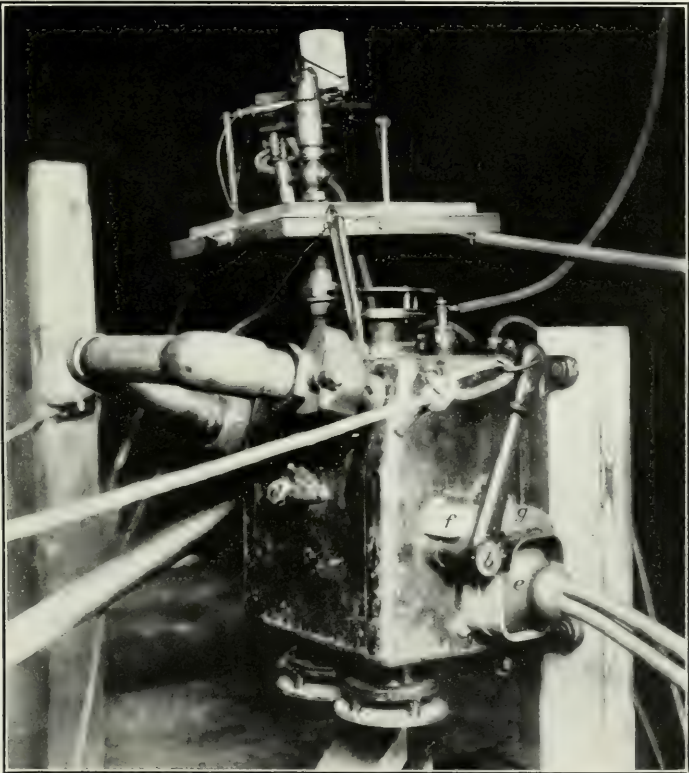
The switch was equipped with three protective devices in the form of conical discharge tubes, or nozzles, each of which was provided with four disks of perforated metal, assembled as shown in figure 1. The devices were attached to the casing, as shown in Plate I, *A*, and furnished a total relief area of 0.356 square inch. The unoccupied space within the switch casing was estimated to be 0.46 cubic foot.



A. SWITCH XD1, FRONT VIEW, EXTERIOR.



B. SWITCH XD1, FRONT VIEW, INTERIOR.



C. SWITCH XD1, READY FOR TEST.

METHOD OF PROCEDURE.

The switch was set up in the testing gallery and connections of 1½-inch pipe were made from two opposite points in the switch casing (Pl. I, *C*) to the intake of the fan. Quick-acting valves were placed in the piping next to the casing so that it could be isolated from the fan piping before the gaseous mixture within the casing was ignited. With these valves open, the action of the fan created a partial vacuum in the casing, which was soon filled with gas drawn in through the openings of the protective devices.

The valves were so arranged that they could be operated from outside the gallery by means of a cord. The switch, in series with the loading rheostat, was connected to a source of direct current and a cord was provided for operating the switch from outside the gallery, so that the gaseous mixture within the switch casing might be ignited by the flash drawn when the switch was operated under load. Some of the tests were made in this manner, but in most of them a spark plug, *h* (Pl. I, *B*) was used for ignition purposes.

In making a test a card was placed on the drum of the recording pressure indicator, the quick-acting valves were opened, the testing gallery was closed, and the fan was started. The gallery was then filled with a properly proportioned mixture of gas and air. The gaseous mixture was then drawn through the switch casing by means of the fan until the gas percentage indicator showed that the casing was filled. All valves were then closed and the explosive mixture in the casing ignited. Observations of the phenomena accompanying the ignition were made and recorded. The maximum pressure developed in the casing by the explosion was determined by applying the proper scale to the curve on the indicator card. The gallery and switch casing were thoroughly aired before making another test.

RESULTS OF TEST.

Only a few tests were made on switch XD1 because the results obtained were so conclusive that nothing was to be gained by making more tests. Results of the tests are shown in the table following:

TABLE 1.—*Conditions and results of tests.*

Test No.	Character of ignition. ^a	Condition of protective devices.	Maximum pressure.	Puncture. ^b
			<i>Pounds per square inch.</i>	
1	S. P.	All open.	14.5	No.
2	Sw. 100	Do.	20.6	Yes.
3	S. P.	Do.	15.25	No.
4	S. P.	Do.	15.0	No.
5	S. P.	Do.	14.6	No.
6	S. P.	Do.	15.0	Yes.
7	Sw. 23.2	One lower plugged.	23.2	Yes.

^a In this column "S. P." indicates spark-plug ignition. "Sw." indicates that the ignition was made by opening the switch under load, and the number following indicates the amperes of current flowing.

^b For the sake of simplicity the term "puncture" has been applied to the ignition of the gaseous mixture surrounding the switch casing by flames discharged from the casing. In any tests where puncture is reported the protective devices failed to perform their safeguarding functions as evidenced by the fact that the gaseous mixture outside the casing was ignited by flames from within.

Flames were observed only at the protective device on the top of the switch, as the observer was not in a position to look into the outlets of the lower protective devices. However, a yellow light was observed to come from under the switch owing to the flames at the lower protective devices. The flames were yellow and did not extend beyond the edge of the baffle plate that protected the device, but extended about one-half or three-fourths of an inch beyond the outer plate of perforated metal. The first two punctures occurred at the lower protective devices. It was not possible to tell where the third puncture occurred.

DISCUSSION OF RESULTS OF TEST.

The results of the tests show that the switch is not suitable for use in gaseous atmospheres. Two punctures were obtained out of six trials made with the switch in its normal condition and another puncture was obtained in a trial made when one of the protective devices had been put out of commission. A puncture occurred in the only test made by igniting the mixture within the switch casing by a flash from the switch contacts when all the protective devices were in use. The protective devices failed to fulfill the purpose of their design, because there was not enough heat absorbing material in each partition of the protective devices and because these partitions were spaced too far apart.

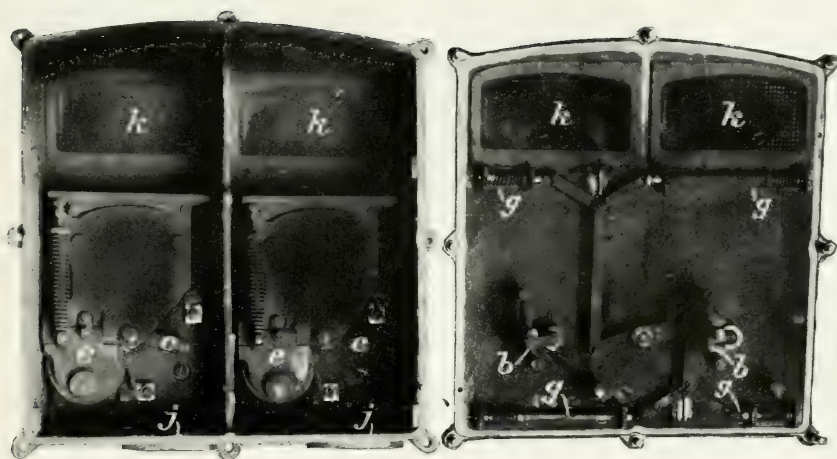
REMARKS ON SWITCH DESIGN.

As regards mechanical strength, the design of the protective devices seemed to be satisfactory. The mechanical design of the devices for preventing the improper manipulation of the switch seemed to be good, although no tests were made to determine the wearing qualities of these devices.

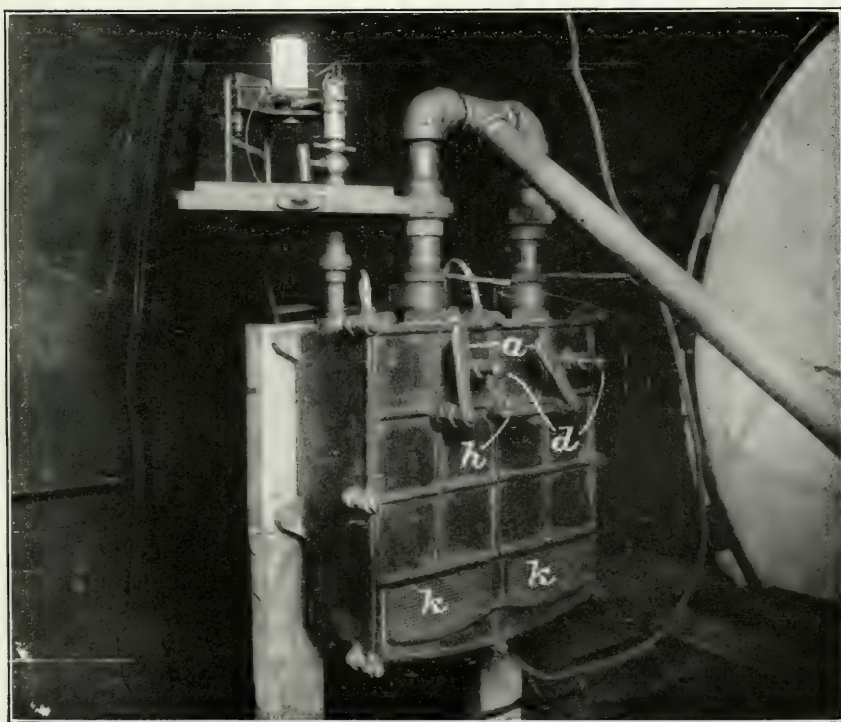
SWITCH XP1.

DESCRIPTION OF SWITCH.

Switch XP1 was composed of two 600-volt, 40-ampere, single-pole, automatic circuit breakers inclosed in a cast-steel casing which was provided with protective devices. The details of construction are shown in Plate II, *A*, *B*. The circuit breakers were closed by the handles, *a* (Pl. II, *B*), which were connected through stuffing boxes in the cover to the forked arms *b*, operating the insulated switch levers, *c* (Pl. II, *A*). The automatic operation of the circuit breakers was accomplished by a solenoid of the usual type which, when excited by a predetermined current, released a latch that held the circuit



A. SWITCH XP1, INTERIOR VIEW.



B. SWITCH XP1, SET UP FOR TEST.

breakers closed. This latch could also be released from outside the casing by pressing upon the knobs, *d* (Pl. II, *B*), to which were connected rods which, passing through stuffing boxes in the cover, gave the latch a motion similar to that imparted by the solenoid.

The cover was secured to the casing by eight $\frac{3}{8}$ -inch cap screws provided with collars to prevent their removal from the cover. Four locking bars, *g* (Pl. II, *A*), operated by the handle, *h*, were also provided and interlocked with the handles, *a* (Pl. II, *B*), so as to prevent not only the removal of the cover while the circuit breakers were closed, but also the closing of the circuit breakers while the cover was removed. Holes, *j* (Pl. II, *A*), were provided at the bottom of the switch casing for the entrance of leads. These holes were tapped for $\frac{3}{4}$ -inch pipe, so that the wires could be run in conduits.

The unoccupied space within the switch casing was about 0.8 cubic foot.

The switch casing was equipped with four protective devices, *k*. These devices consisted of an outside plate of perforated brass about $\frac{1}{16}$ inch thick, immediately inside of which were two layers of 70-mesh copper gauze. Each plate of brass was perforated with 545 holes, approximately $\frac{1}{8}$ inch in diameter, spaced 0.2 inch apart. The total area of relief openings afforded by these devices was about 12.64 square inches.

METHOD OF PROCEDURE.

The procedure in the tests on switch XP1 was the same as that followed in the tests made on switch XD1 (page 11).

RESULTS OF TESTS.

Below are enumerated the conditions under which the tests were made, the maximum pressures developed by the explosion within the switch casing, the phenomena accompanying the explosion, and whether or not "puncture" (see Table 1, footnote ^b, page 11) occurred.

Eighty-five tests were made on this switch under five different conditions. Eighty tests were made by ignition of the mixture from a flash at the contacts of the circuit breakers when they automatically opened. Five tests were made by ignition from a spark plug. Most of the tests were made with a gaseous mixture containing 8.6 per cent gas, which was believed to be the most explosive mixture. Some tests, however, were made with more and some with less than 8.6 per cent gas, in order to observe the effect of slow-burning mixtures. Some tests were made with coal dust sifted into the protective devices, in order to observe whether the dust particles would, while incandescent, be blown through the protective devices and ignite the gaseous mixture surrounding the switch casing.

In none of the tests were any flames seen to issue from the switch casing. In all tests the pressure developed within the switch casing by the explosion was comparatively low, due to the relatively large relief area of the protective devices.

In almost every test, immediately following the initial explosion, a burning of gas, accompanied by a loud humming noise lasting about 3 or 4 seconds, was seen at the inner face of the protective devices. The flames were blue, sometimes having a tinge of green toward the last, and appeared to move inward and upward. This is termed "afterburning." In those tests made with coal dust in which afterburning occurred, the flames appeared red, due to the incandescent dust particles. In all tests, except those made with coal dust, the flame of the initial explosion was reddish purple. When dust was used the initial flame was red.

In making the tests of group 2 (Table 2) it was found that the occurrence of afterburning depended on the quantity of dust that was sifted into the protective devices. When only a small quantity of dust was used afterburning occurred, but when a large quantity was used afterburning did not occur; also the presence of dust had a tendency to reduce the maximum pressure developed. In the tests made with 8.6 per cent gas alone, the average maximum pressure was 4.1 pounds; in the tests made with 8.6 per cent gas and a little dust, the average maximum pressure was 3.3 pounds; and in the tests made with 8.6 per cent gas and a large proportion of dust, the average maximum pressure was 2.7 pounds.

TABLE 2.—Results of tests of switch XP1.

Group No.	Gas.	Character of ignition. ^a	Maximum pressure. ^b	Number of tests made.	Number of punctures. ^c	Afterburning.
	<i>Per cent.</i>		<i>Pounds per square inch.</i>			
1	8.6	Sw.	4.12	35	0	Yes.
^d 2	8.6	Sw.	3.18	15	0	8 Yes; 7 No.
3	8.6	Sp.	2.56	5	0	Yes.
4	7.0	Sw.	1.24	15	0	Yes.
5	10.0	Sw.	.67	15	0	Yes.

^a In this column "Sp." indicates spark plug ignition. "Sw." indicates that the ignition was made by automatically opening the switch under load.

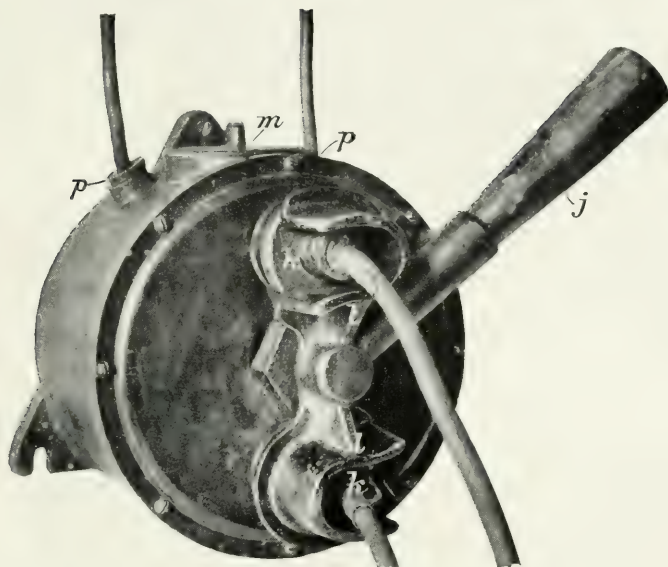
^b The values given in this column are the average of all the maximum pressure observed in the tests of each group.

^c See Table 1, footnote b.

^d In this group of tests finely ground coal dust was sifted into the protective devices before each test.

The protective devices fulfilled the purpose of their design in that no puncture was obtained from 85 trials.^a

^a This statement, based upon the preliminary tests, does not mean that the switch is regarded as permissible for use in gaseous mines. Tests to establish a list of permissible electric switches are now being considered. (See section of this report headed "Permissible Switches for Use in Gaseous Mines," p. 30.)



A. SWITCH OD1, EXTERIOR VIEW.



B. SWITCH OD1, INTERIOR VIEW.

REMARKS ON SWITCH DESIGN.

The merits of the design are as follows: The ratio of relief opening area (12.64 square inches) to unoccupied space within the casing (0.8 cubic foot) is commendably high. Fine gauze (70-mesh) reinforced by perforated metal sheets appears to be an efficient device for absorbing heat.

The weak points in the design are as follows: The heat-absorbing material (perforated plates and gauzes) is not sufficiently protected from mechanical injury. The gauzes should be reinforced by a sheet of perforated metal on each side instead of on one side only. The unoccupied space within the switch casing appears to be greater than is necessary. The locking bars *g*, (Pl. II, *A*), alone did not draw the cover close enough to the casing to prevent the passage of flames. It was possible to open and close the circuit breakers while the cover of the switch casing was removed.

SWITCH OD1.

DESCRIPTION OF SWITCH.

This switch was a double-pole, single-throw, double-break oil switch, rated 100 amperes at 250 volts. The details of construction are shown in Plate III, *A* and *B*. The leads on the generator side of the switch passed through rubber-bushed holes, *p*, and connected with clips, *a*, mounted on fiber blocks. When the switch was closed, the blades, *c* and *d*, fitted into clips, *a* and *b*, respectively. The fuse holder, *e*, was provided with clips and these fitted onto knife blades, *f*. The various clips and blades were fastened in place and electrically connected by screws or rivets passing through the fiber insulators, *g*. All the moving parts were mounted on the shaft, *h*, which had a bearing at *i*, passed through a stuffing box in the cover, and had the handle, *j*, attached to its outer end. The load connection was made with attachment plugs, *k*, that fitted tightly into their receptacles, which were a part of the bases of clips, *b*. The wings, *l*, on the handle casting prevented the insertion or the removal of the plugs while the circuit was closed. The casing was of cast iron and was provided at the top with an opening, *m*, for putting in the oil and for renewing the fuses. This opening was closed by a screw cap. The fuses were mounted in such a position that they were accessible through this opening only when the switch was open. A plugged hole, *n*, provided a means for drawing off the oil without dismounting the switch. The cover was secured in place by screws and made tight by a lead gasket. The handles of the attachment plugs and the metal parts of the receptacles were protected by coverings of hard rubber. The grip of the handle was of hard wood. The casing could hold about 2.85 liters (approximately 3 quarts) of oil.

METHOD OF PROCEDURE AND RESULTS.

The switch was set up in the testing gallery and arranged so that it could be connected in series with the loading rheostat across the mains of a 200-kilowatt, 225-volt, direct-current generator. The rheostat was adjusted so that a current of 100 amperes flowed through the switch when it was closed. The switch was tested by opening and closing it by mechanical means about 8 times a minute. The test was continued in this manner until the switch had been opened and closed 28,980 times. During the progress of the test the switch contacts were renewed four times, but the oil was not changed. The life of each set of contacts was as follows:

Number of operations made with each set of contacts.

Contacts used.	Number of operations.
First set.....	2, 453
Second set.....	4, 939
Third set.....	10, 878
Fourth set.....	4, 489
Fifth set.....	6, 221
Total.....	28, 980

The temperature of the air that surrounded the switch varied from 10° C. in some tests to 24° C. in others. The average temperature of the oil throughout the tests was 33° C., the maximum being 87° C. when the contacts had become badly burned. The last 6,221 operations were made with the screw cap removed and the switch casing surrounded by the most explosive mixture of gas and air. The gas was not ignited in any test. Since no ignition occurred during the last 6,221 tests, it is probable that none would have occurred had gas been present during the 22,759 previous tests, and hence the test was equivalent to 28,980 operations in explosive gas.

The test was started with 3.25 liters (approximately 3 quarts) of oil ^a in the casing. Each time the contacts were changed some of the oil was unavoidably lost. Had this oil not been replaced it would have imposed an unfair condition upon the switch, and as it was almost impossible to determine the amount of oil lost during the process of renewing the contacts it was decided that after each such renewal the oil level should be brought up to its original height. This makes each series of runs, made with a single set of contacts, a test by itself, although in the latter runs the greater part of the oil had seen service on all previous runs. As many as 10,000 operations were made without lowering the oil level enough to expose the contacts, and as this may be taken to represent about three

^a The analysis of this oil (No. 14-0) is given in Table 3.

years' service on a basis of 10 operations per day, it is reasonable to assume that the oil would be replenished before it had fallen to a dangerously low level through the operation of the switch.

During the first 22,000 operations about 250 c. c. (approximately one-half pint) of oil was forced out of the casing around the bushings provided for the incoming leads. No appreciable leakage occurred around the joint between the cover and the casing. The condition of the oil after the test had been made is shown in Table 4.

DISCUSSION OF RESULTS OF TEST.

The results of the tests indicate that as long as the switch contacts are submerged in the oil the switch, within its rated capacity, can safely be used in gaseous atmospheres.^a

The absolute safety of the switch is, however, conditional upon the presence of oil in proper quantities. The tests show that the loss of oil due to evaporation and to the operation of the switch will not reduce the oil level to a dangerous point before the switch contacts have become so burned that the circuit can not be closed. The safety of the switch therefore depends largely upon the care that is taken to prevent the accidental loss of oil from the switch.

REMARKS ON SWITCH DESIGN.

The design of the switch is well suited to mine use. With one exception the mechanical strength of the parts seems to be sufficient to withstand the rough usage incident to underground service. The exception noted is the bushing provided for the incoming leads. It is suggested that the bosses on the casing be lengthened to allow a steel cap to be threaded onto each boss, and that the bushings be made of fiber and held between the caps and the face of the bosses. By this means the bushings would be held rigidly in place and protected from mechanical injury. It is further suggested that the switch contacts be placed so that each will be submerged in the oil to the same depth. This will have the effect of increasing the depth of oil over the contacts.

So far as was observed during the tests the joint between the cover plate and the casing allowed almost no leakage of oil. If the switches are not abused, the loss of oil from this joint should be very slight. The fuses were not tested, but it is recommended that inclosed fuses rather than open fuses be applied to this switch if such an arrangement is practicable.

^a This statement, based upon the preliminary tests, does not mean that the switch is regarded as permissible for use in gaseous mines. See footnote a, page 14.

SWITCH OD2.

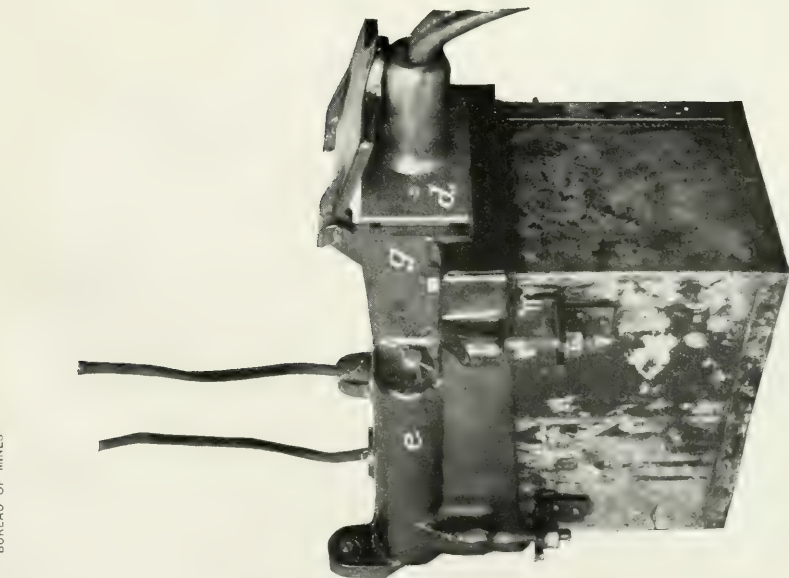
DESCRIPTION OF SWITCH.

This switch was a double-pole, single-throw, 100-ampere, 600-volt, finger-contact, automatic oil switch. The details of construction are shown in Plate IV, *A* and *B*. The fingers *a* served to make the connection between the incoming terminals, *b*, and the load terminals, *c*, on the attachment plug, *d*. These fingers were mounted on a carriage that was, by the insertion of the plug, pushed backward against springs in chamber, *e*. Just after the plug entered its receptacle, *g*, the terminals, *c*, made connection with the contacts on the upper ends of the fingers, *a*, and at the same time the end of the plug came in contact with the end of the carriage upon which the fingers were mounted. By thrusting the plug farther into its receptacle the carriage was pushed backward until the fingers came in contact with the terminals, *b*, completing the circuit. The plug was held in position by a latch that engaged the tooth, *f*. When the switch was opened by hand, a slight upward pressure on the handle of the plug disengaged the latch, allowing the springs to force the carriage and plug outward, breaking the circuit between *a* and *b*, which were under oil. Thus the operation of the switch was accomplished by the insertion and removal of the plug. In the automatic opening of the switch the latch was disengaged by the release coil, *h*, and the operation completed as in the case of hand operation.

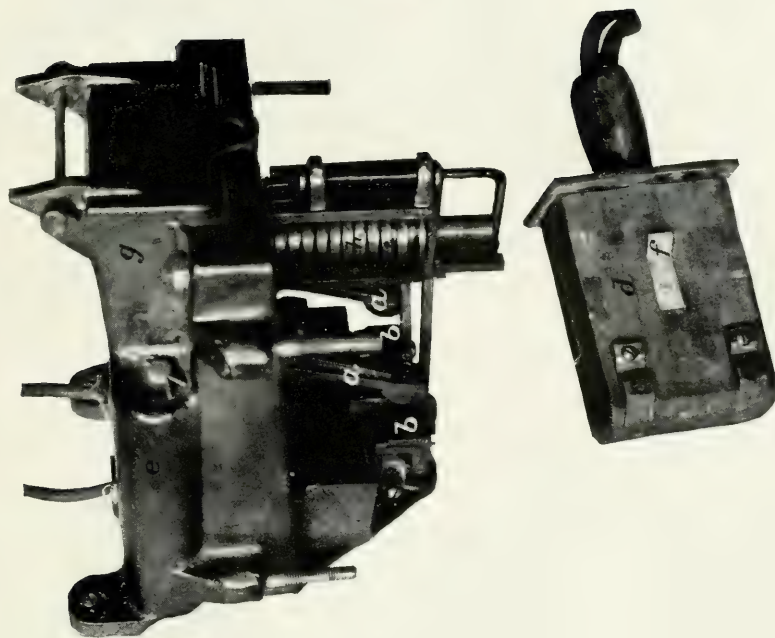
The attachment plug was of hard wood. The switch frame was of cast iron. The oil tank was of sheet metal with riveted and soldered seams, and could hold, up to the height designated by the manufacturer, about 4.7 liters (approximately 1½ gallons) of oil.

METHOD OF PROCEDURE AND RESULTS.

The only test made upon this switch was a test to determine the evaporation of oil from the oil tank. The tank was filled with fresh oil and the switch placed in the evaporation house, where the temperature was maintained at 37° C. for 23 days and at 85° C. for 52 days of 24 hours each. The analyses of the oil (No. 15-0) before and after test are given in Table 3. This switch was examined after all the other oil switches had been tested. The previous tests demonstrated that as long as the contacts of oil switches of this capacity are covered to a reasonable depth with oil, flashes from the switch contacts can not ignite gas. These tests and the evaporation test made on this switch have also shown that the loss of oil due to evaporation and to the operation of the switch will not reduce the oil level to a dangerous point before the switch contacts have become so burned that the circuit can not be closed. In the light of the previous tests



4. SWITCH OD2, EXTERIOR VIEW.



SWITCH OD2, INTERIOR VIEW.

and from an examination of the switch and an analysis of the oil this oil switch as submitted should operate safely in gaseous atmospheres when carrying and breaking a current of 100 amperes from a 250-volt generator of at least 200-kilowatt capacity (the capacity of the generator available for the tests), and possibly from generators of greater capacity, especially if the switch were set up at some distance from the generator.^a

The safety of the switch depends entirely upon the care that is taken to insure the presence of enough oil. The presence or absence of oil can not be seen by a glance at the exterior of the switch and can be determined only by removing the oil tank.

The safety of the switch is therefore conditional upon proper inspection, which can not be assured by test, and hence the absolute safety of the switch can not be vouched for.

REMARKS ON SWITCH DESIGN.

The design seems sufficiently simple and some of the parts are no doubt mechanically strong enough as submitted. The mechanism for preventing flashes from the contacts of the removable plug seems to perform its function. It is probable that the manufacturers contemplate further development of the switch before placing it upon the market. The removable plug seems to be the weakest and least developed part of the equipment, and must be materially improved in design and construction before it will be able to withstand satisfactorily the severities of underground service.

SWITCH OP1.

DESCRIPTION OF SWITCH.

This switch was a two-pole, 250-volt, 50-ampere, knife-blade, nonautomatic oil switch. The details of construction are shown in Plate V, A. The current-carrying parts were mounted on a porcelain base, *b*, approximately 5 by 5½ by 1½ inches, with the blades, *a*, and clips, *c*, on the under side, so that the arc was formed under about 4 inches of oil when the oil tank was filled to the height designated by the manufacturer. A wooden rod, *d*, for operating the blades passed through a hole in the center of the porcelain base. The leads entered the switch through porcelain bushings, *e*, at the top, and connected with connection sleeves on the upper side of the base.

The oil tank was made of sheet iron with welded seams and was secured to the switch frame by two bolts. The tank held about 2.9 liters (approximately 3 quarts) of oil^b when filled to the height designated by the manufacturers.

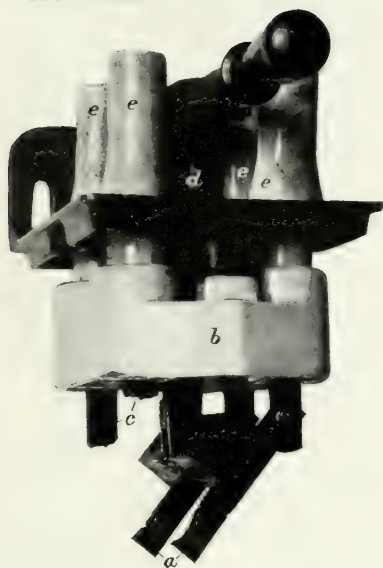
^a This statement, based upon the preliminary tests, does not mean that the switch is regarded as permissible for use in gaseous mines. See footnote *a* on page 14.

^b The analysis of the oil (No. 11-0) used in this switch is given in Table 3.

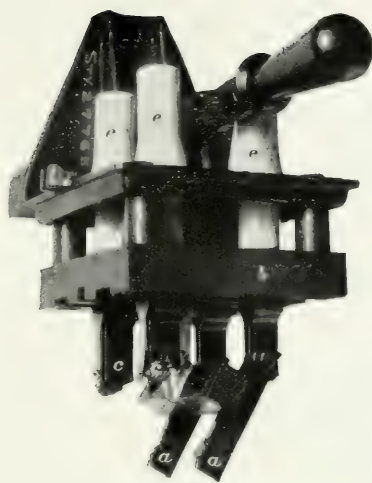
METHOD OF PROCEDURE AND RESULTS.

The switch was set up in the testing gallery and arranged so that it could be connected in series with the loading rheostat across the mains of a 200-kilowatt, 225-volt, direct-current generator. The rheostat was provided with an automatic device that allowed only 20 amperes to flow when the switch was first closed, but raised the current to 100 amperes just before the switch was opened. A tube was inserted through the side of the oil tank so that a thermometer could be suspended near the arc points of the switch contacts.

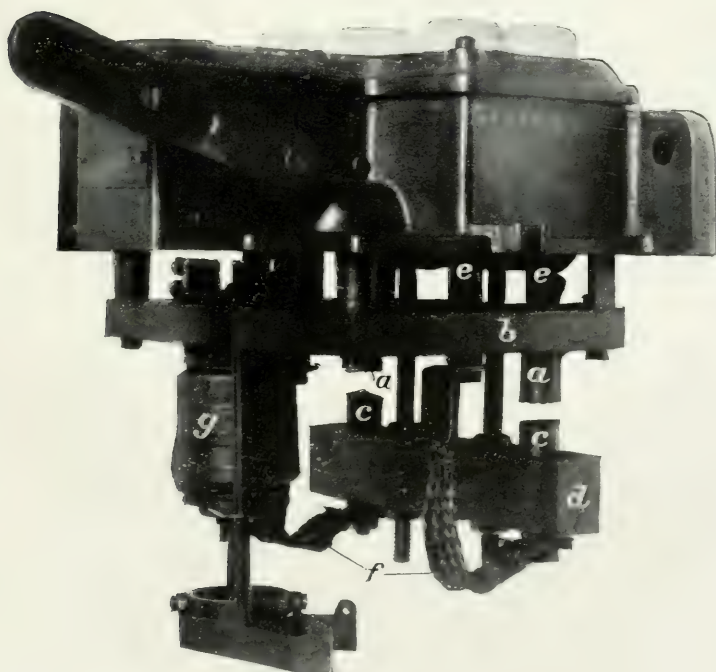
The switch was tested by opening and closing it by mechanical means about 11 times a minute. The test was continued in this manner until the switch had been operated 75,000 times. At frequent intervals explosive mixtures of gas and air were introduced to the testing gallery. No ignition occurred, as the oil level did not fall low enough to expose the contacts. At the end of the test the contacts were still submerged in oil to a depth of about $3\frac{1}{4}$ inches. The temperature of the air that surrounded the switch varied from -7° C. in some tests to 38° C. in others. The average temperature of the oil near the contacts was 17° C., the maximum being 77° C. when the contacts had become badly burned. During the progress of the test the switch contacts were renewed four times, but the oil was not changed. The following table shows the physical and chemical properties of the oils used in testing oil switches:



A. SWITCH OP1, INTERIOR VIEW.



B. SWITCH OP2, INTERIOR VIEW.



C. SWITCH OP3, INTERIOR VIEW.

TABLE 3.—Analyses of oils *a* used with switches tested.

Physical and chemical properties of the switch oils.																	
Designating No. of oil used.	Switch in which oil was used.	Fractional distillation.															
		Specific gravity at 15° C.	Viscosity (°Engler at 20° C.).	Water.	Sulphur.	Acidity or alkalinity.	Fractions distilled at increasing temperatures.						Residue.	Loss.			
							Pressure (mm. of mercury).	225-250° C.							250-275° C.	275-300° C.	300-325° C.
								Per cent.	Per cent.	Per cent.	Per cent.	Per cent.					
11-0.....	OP1	0.8760	8.0	0	0.04	Neutral....	10	24.2	28.7	13.9	9.9	23.1	0.2				
11-0.....	OP2	.8760	8.0	0	.04	do.....	10	24.2	28.7	13.9	9.9	23.1	.2				
12-0.....	b OP3	.8575	4.6	0	Trace.	do.....	20	11.8	47.1	24.5	13.4	3.1	.1				
12-0.....	c OP3	.8575	4.6	0	Trace.	do.....	20	11.8	47.1	24.5	13.4	3.1	.1				
13-0.....	OP4	.9290	18.0	0	.19	do.....	14	26.2	31.9	24.1	15.2	2.3	.3				
14-0.....	OD1	.9020	416.3	Trace.	.06	do.....	12	0	0	0	0	100.0	0				
15-0.....	OD2	d. 8725	9.1	0	.04	do.....	14	0	35.0	35.3	23.9	5.7	.1				
Physical and chemical properties of the switch oils.																	
Designating No. of oil used.	Condition at 0° C.	Free carbon.		Flash point. ^e		Ignition point. ^f	Loss during test.		Number of operations made.	Number of gallery ignitions.							
		Before test.	After test.	Before test.	After test.		Operation test.	Evaporation test.									
					° C.						° C.						
												Per cent.	Per cent.				
11-0.....	Liquid.....	0	4.45	158	135	202	.....	.....	75,000	0							
11-0.....	do.....	0	3.95	158	132	202	.....	2.2	75,000	0							
12-0.....	do.....	0	4.19	170	105	195	.....	4.0	3,471	1							
12-0.....	do.....	0	3.89	170	145	195	.....	3.9	2,775	1							
13-0.....	do.....	0	4.35	166	85	187	.....	9.8	75,000	0							
14-0.....	Solid.....	Trace.	1.06	255	120	325	14.7 (?)	.....	28,980	0							
15-0.....	Liquid.....	0	.27	185	187	215	.....	4.3	0	.....							

^a Analyses made by W. A. Jacobs, Bureau of Mines chemist.^b First series.^c Second series.^d Gravity after evaporation test was 0.8745.^e Pensky-Martens closed tester.^f Pensky-Martens open tester.

TABLE 4.—Carbonization of No. 11-0 oil during the progress of the tests in which the oil was used.

Designating No. of oil.	Switch in which the oil was used.	Per cent free carbon.													
		After 5,000 operations.	After 10,000 operations.	After 15,000 operations.	After 20,000 operations.	After 25,000 operations.	After 30,000 operations.	After 35,000 operations.	After 40,000 operations.	After 45,000 operations.	After 50,000 operations.	After 55,000 operations.	After 60,000 operations.	After 65,000 operations.	After 75,000 operations.
11-0.....	OP1	0.20	.....	1.40	a 1.30 1.19	1.46 1.27	1.62	1.95 1.70	2.73 1.84	a 2.49 2.06	2.91 2.29	2.95 2.86	a 4.94 2.98	3.82 3.06	4.45 3.95
11-0.....	OP2	.....	0.53	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

^a The inconsistency of these results is probably due to the fact that a homogeneous sample of the oil was not obtained.

After each 5,000 operations a 26-gram (approximately 1 ounce) sample of oil was removed from the oil tank to determine the percentage of free carbon, 26 grams of fresh oil being added in each case. The results are shown in Table 4.

The life of each set of contacts was as follows:

Number of operations made with each set of contacts.

Contacts used.	Number of operations.
First set.....	^a 13, 135
Second set.....	32, 503
Third set.....	9, 942
Fourth set.....	11, 680
Fifth set.....	^b 7, 740
Total.....	75, 000

DISCUSSION OF RESULTS OF TEST.

The results of the tests indicate that as long as the switch contacts are submerged in oil to the depth recommended by the manufacturers the switch, within its rated capacity, can safely be used in gaseous atmospheres.^c

The absolute safety of the switch is, however, conditional upon the presence of oil in proper quantities. The tests show that the loss of oil due to evaporation and to the operation of the switch will not reduce the oil level to a dangerous point before the switch contacts have become so burned that the circuit can not be closed. The safety of the switch therefore depends largely upon the care that is taken to prevent the accidental loss of oil from the switch.

REMARKS ON SWITCH DESIGN.

This switch was not designed especially for mine service and is not well adapted for rough usage. If mounted upon a switchboard in a well-constructed underground substation the switch should prove as satisfactory as if set up above ground, but for general use here and there about a mine under haphazard conditions of installation, such as mounting upon mine timbers or roughly constructed supports, the construction ought to be more substantial and the casing nearly airtight in order to preclude the loss of oil.

^a Plate V, A, shows the condition of this set after the 13,135 operations had been made.

^b This set was not burned off at the completion of the test.

^c This statement, based upon the preliminary tests, does not mean that the switch is regarded as permissible for use in gaseous mines. See footnote a, page 14.

SWITCH OP2.

DESCRIPTION OF SWITCH.

Switch OP2 was a two-pole, 6,600-volt,^a 100-ampere, knife-blade, nonautomatic oil switch.

The details of construction are shown in Plate V, *B*. The switch was similar to switch OP1, except that the base was of hard wood. A wooden barrier about one-half inch thick separated the blades and clips of opposite polarity, thus dividing the oil tank into two parts. The oil tank was similar in construction to that of switch OP1, the inside dimensions were 7 by 7 by 9 inches, and the tank was lined throughout with fiber about $\frac{1}{16}$ inch in thickness. The tank held about 4.65 liters (approximately 5 quarts) of oil^b when filled to the height designated by the manufacturers.

METHOD OF PROCEDURE AND RESULTS.

This switch was tested in exactly the same way as was the switch OP1. No ignition of the gaseous mixture occurred, as the oil level did not fall sufficiently to expose the contacts. At the end of the test the contacts were still submerged in oil to a depth of about $3\frac{1}{4}$ inches. The temperature of the air that surrounded the switch varied from -1° C. in some tests to 38° C. in others. The average temperature of the oil near the contacts was 31° C., the maximum being 110° C. when the contacts had become badly burned. During the progress of the test the switch contacts were renewed twice, but the oil was not changed. The life of each set of contacts was as follows:

Number of operations made with each set of contacts.

Contacts used.	Number of operations.
First set.....	c 13, 650
Second set.....	51, 350
Third set.....	d 10, 000
Total.....	75, 000

After each 5,000 operations a 26-gram (about 1 ounce) sample of oil was removed from the oil tank to determine the percentage of free carbon, 26 grams of fresh oil being added in each case. The results are shown in Table 4.

DISCUSSION OF RESULTS OF TEST.

The remarks on the results of the test of switch OP1, page 23, apply equally well to switch OP2.

^a Although this was the standard rating of the switch it was offered for test as a 250-volt switch.

^b The analysis of the oil (No. 11-0) used in this switch is given in Table 3.

^c Plate V, *B*, shows the condition of this set after the 13,650 operations had been made.

^d These contacts were still in good condition when the test was completed.

REMARKS ON SWITCH DESIGN.

The remarks on the design of switch OP1, page 23, apply equally well to the design of switch OP2.

SWITCH OP3.

DESCRIPTION OF SWITCH.

This switch was a two-pole, 600-volt,^a 100-ampere oil switch provided with an automatic overload release. The details of construction are shown in Plate V, *C*. The current-carrying parts were mounted on the under side of a wooden base *b*, approximately $6\frac{3}{4}$ by $7\frac{1}{4}$ by $\frac{3}{4}$ inches. When the oil tank was filled to the designated level the contacts were submerged to a depth of about 2 inches.

The contact was a butt contact between two brass cylinders, *a* and *c*, about $\frac{3}{4}$ inch in diameter and 1 inch in length. The stationary contacts, *a*, were fastened directly against the lower side of the base by studs that passed through the base and terminated on its upper side in connection sleeves. The movable contacts, *c*, were supported on a wooden bar, *d*, and held in place against a spring (concealed in the bar) by studs that passed through the bar and connected through flat woven-wire braids, *f*, with the sleeves, *e*, to which were fastened the conductors entering the switch casing. The bar, *d*, was operated by two rods that passed through holes in the base and were attached to an operating lever. On one pole of the switch between the connection sleeve and the movable contact was located a solenoid, *g*, designed to open the switch on overload. The armature of this solenoid could be adjusted to act at any value of current between 80 and 160 amperes.

The frame of the switch was made of cast iron and was provided with six porcelain-bushed holes for the entrance of leads.^b

The oil tank was made of sheet iron with welded seams. It measured 7 by $7\frac{1}{2}$ by 8 inches and held about 5.25 liters (approximately $5\frac{1}{2}$ quarts) of oil ^c when filled to the height designated by the manufacturers.

METHOD OF PROCEDURE AND RESULTS.

The switch was set up in the testing gallery and arranged so that it could be connected directly across the mains of a 200-kilowatt, 225-volt, direct-current generator. The resistance of the mains connecting the generator and the switch was measured and found to be about 0.37 ohm. The switch was tested by closing it and then

^a Although this was the standard rating of the switch it was offered for test as a 250-volt switch.

^b The switch was evidently designed originally for three-phase service and had been only partly remodeled before submitting it for test.

^c The analysis of the oil (No. 12-0) used in this switch is given in Table 3.

connecting it across the mains of the generator. After the rush of current had caused the switch to open automatically the connection between the switch and the generator was broken, the switch was once more closed, and the connection between switch and generator was again completed. The switch was manipulated by mechanical means at a rate of about 12 times a minute. An oil gage was attached to the oil tank in order that the change in height of the oil might be observed as the test progressed. By means of this gage the depth of oil in the tank could be determined with an accuracy of 1 per cent.

Arrangements were made for forcing an explosive mixture of gas into that part of the casing of the switch not occupied by oil. The testing gallery was not kept full of gas throughout all the tests because the explosive mixture would soon have been vitiated by the finely divided carbon that was given off in large quantities in a vapor-like form during the operation of the switch. It was considered best to operate the switch for a time and then to remove the carbon-charged air from the gallery and fill it with explosive gas, after which the operation of the switch was continued for another period before once more clearing the gallery and introducing more gas.

Two series of tests were made upon this switch. In the first series the automatic release was set to act at 160 amperes. The oil tank was filled with 5.2 liters (approximately $5\frac{1}{2}$ quarts) of oil. The following table gives the rate of oil loss as the test proceeded and the number of times that gas was introduced into the gallery during the test:

TABLE 5.—Rate of oil loss and number of operations made in gas while operating switch OP3, first series.

Number of operations.	Loss of oil.	Number of operations made in gas.	Ignition of gas.
	<i>C. c.</i>		
0- 100	300	0	....
101- 520	350	0	....
521- 960	50	0	....
961-1,455	50	0	....
1,456-2,073	100	2,044-2,073	No.
2,074-2,560	70	0	....
2,561-3,470	30	2,561-2,600	No.
3,471	....	3,471	Yes.
	950		

After the gas had been ignited the switch was examined. It was found that the arc was formed just at the surface of the oil. As the ignition occurred on the first break after the introduction of the gas, and as nearly 900 breaks had been made just previously without gas in the gallery, the test was repeated in order to obtain more accurate data in regard to the number of times that the switch could be operated without igniting the gas.

The second test of this switch was made under the same conditions as the first. The following table shows the rate of oil loss and the number of times that gas was introduced to the gallery during the test:

TABLE 6.—Rate of oil loss and number of operations made in gas while operating switch OP3, second series.

Number of operations.	Loss of oil.	Number of operations made in gas.	Ignition of gas.
	<i>C. c.</i>		
0- 300	630	0	....
301- 590	70	0	....
591-1, 270	70	0	....
1, 271-2, 260	110	0	....
2, 261-2, 773	40	{ 2, 261-2, 280 2, 664-2, 683	No.
2, 774-2, 775	....		No.
	920	2, 774-2, 775	Yes.

After the switch had been operated 2,773 times gas was introduced in the gallery. The 2,774th operation did not cause the gas to ignite but the 2,775th operation did. An examination of the switch showed that the arc was formed under about $\frac{1}{16}$ inch of oil.

Fourteen times during the progress of the tests the switch contacts became so burned that they failed to complete the circuit, and it was necessary to adjust or renew them before the test could proceed. The number of operations made between each adjustment or renewal were as follows:

Life of contacts used in switch OP3 during the tests.

No. of test.	Number of operations.	Remarks.	No. of test.	Number of operations.	Remarks.
1	0	(a)	2	1, 050	Adjusted.
1	520	Contacts adjusted.	2	1, 270	Renewed.
1	1, 455	Do.	2	1, 552	Adjusted.
1	2, 073	Renewed.	2	2, 206	Do.
1	2, 560	Adjusted.	2	2, 260	Adjusted 1 pole, renewed 1 pole.
1	3, 471	Test completed.	2	2, 405	Contacts adjusted.
2	0	Contacts renewed.	2	2, 663	Do.
2	300	Adjusted.	2	2, 775	Test completed.
2	590	Do.			
2	640	Renewed.			

^a The contacts that were on this switch when the test was started had been used for 650 operations previous to the beginning of this test.

DISCUSSION OF RESULTS OF TEST.

The remarks on the results of the tests of switch OP1 (p. 23) apply equally well to switch OP3.

REMARKS ON SWITCH DESIGN.

This switch was not especially designed for mine service. In fact it was not originally designed for direct-current service at all, but was a three-phase alternating-current switch adapted to direct-current service by removing one set of contacts and one of the overload release solenoids. The remarks on design of switch OP1 (p. 23) apply also to switch OP3.

SWITCH OP4.

DESCRIPTION OF SWITCH.

Switch OP4 was a three-pole, double-break, 250-volt, 100-ampere, nonautomatic oil switch of the manhole type. The details of construction are shown in Plate VI, *A*, *B*. The eccentric rod, *a*, opened and closed the switch by lowering and raising the wooden rods, *c*, which were attached to the contact brushes, *b* (Pl. VI, *B*). The eccentric rod was operated by the handle, *d*, on the outside of the switch casing (Pl. VI, *A*). The casing was made of cast iron about $\frac{5}{16}$ inch in thickness. The cover was provided with a lead gasket and secured by stud bolts. In setting up this switch in practice the lead sheath of the cable would be soldered to the brass sleeves, *e* (Pl. VI, *A*). The tank held about 7.5 liters (approximately 2 gallons) of oil ^a when filled to the height designated by the manufacturers.

METHOD OF PROCEDURE AND RESULTS.

The switch was installed in the testing gallery and arranged so that it could be connected, in series with the loading rheostat, across the mains of a 200-kilowatt, 225-volt, direct-current generator. The rheostat was adjusted so that 100 amperes flowed through the switch when it was closed.

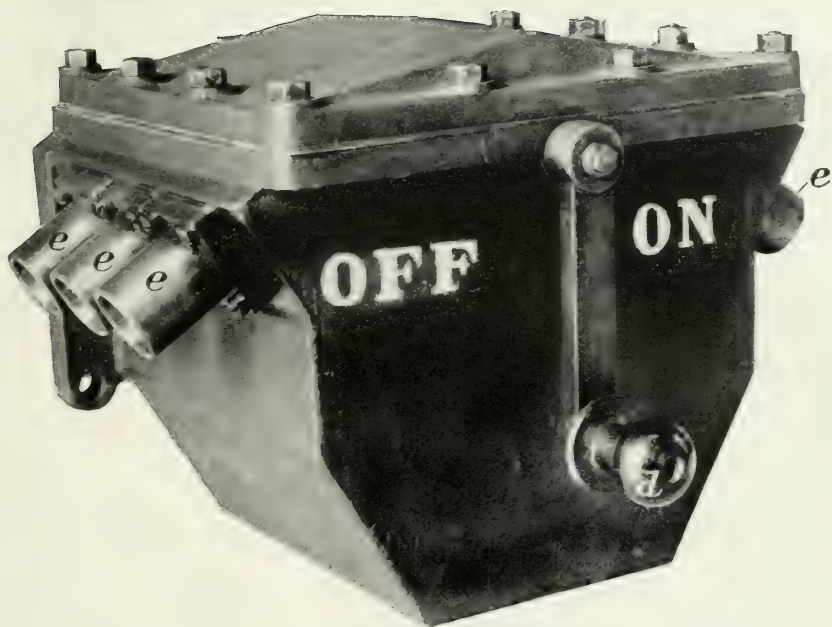
The switch was tested by opening and closing it by mechanical means at a rate of about 10 operations per minute. The test was continued in this manner until the switch had been opened and closed 75,000 times. During the progress of the test the switch contact brushes were renewed three times, but the oil was not changed. The life of each set of contact brushes was as follows:

Number of operations made with each set of contacts.

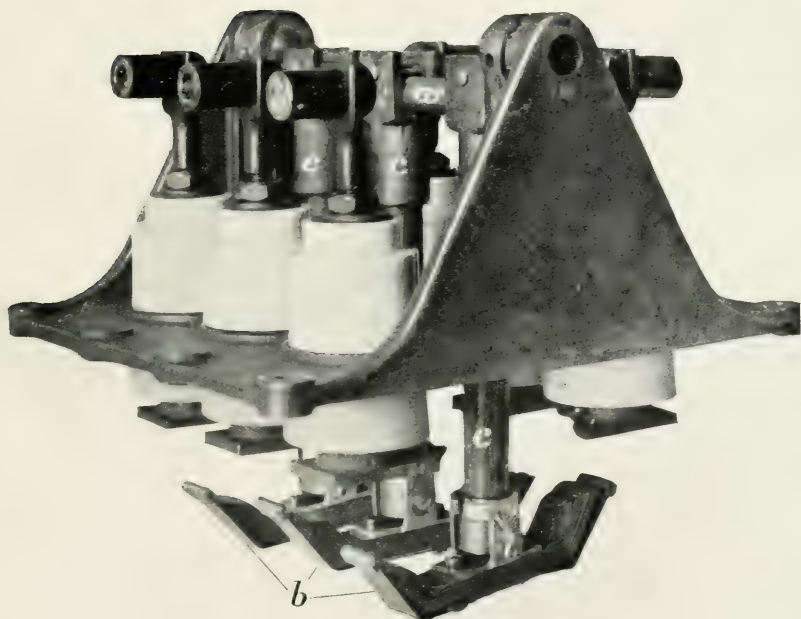
Contacts used.	Number of operations.
First set.....	25, 250
Second set.....	13, 019
Third set.....	31, 731
Fourth set <i>b</i>	5, 000
Total.....	75, 000

^a The analysis of the oil (No. 13-0) used in this switch is given in Table 3.

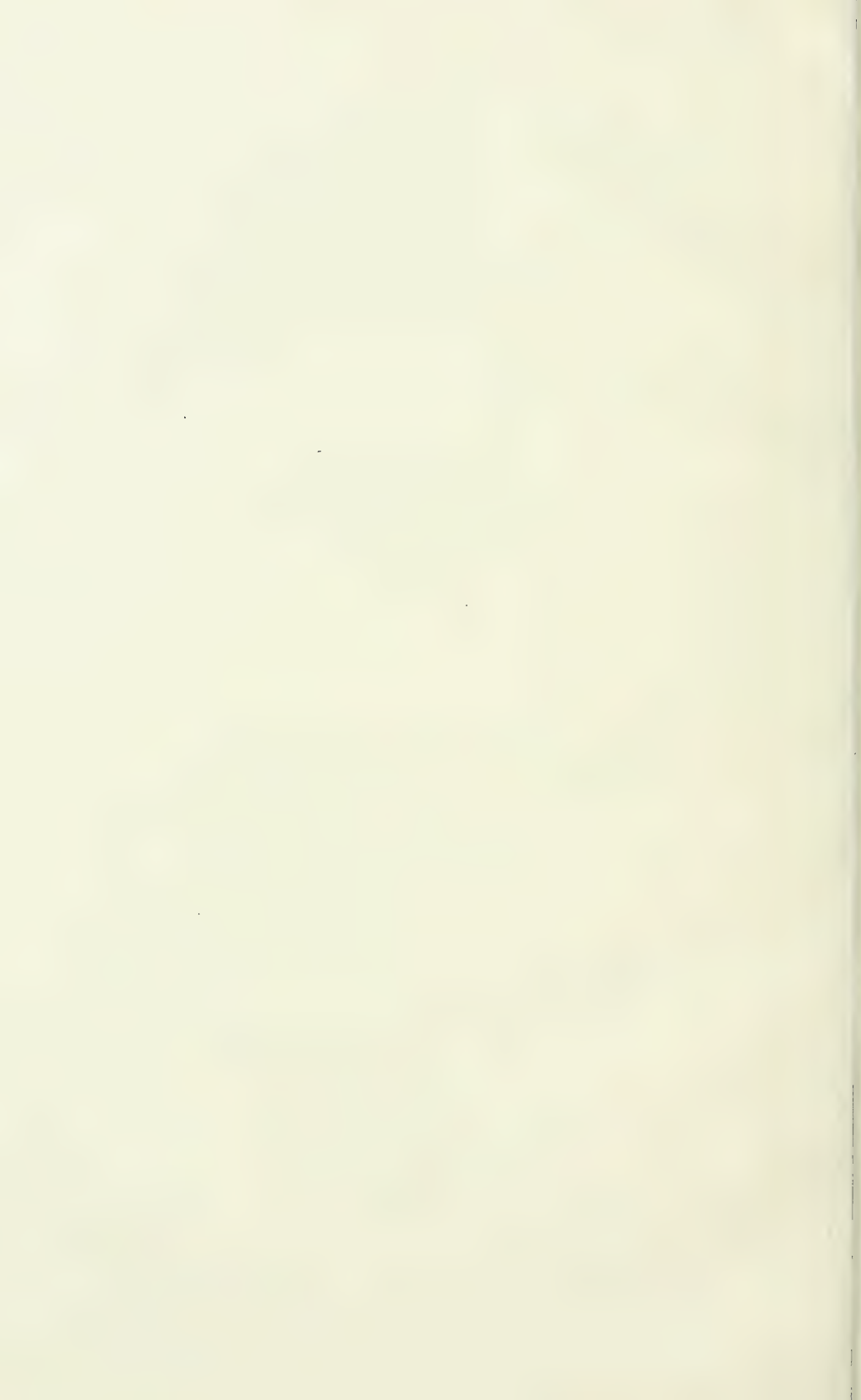
^b This set was still in good condition at the completion of the test.



A. SWITCH OP4, EXTERIOR VIEW.



B. SWITCH OP4, INTERIOR VIEW.



The temperature of the air that surrounded the switch varied from -3°C . in some tests to 22°C . in others. The average temperature of the oil throughout the tests was 35°C ., the maximum being 91°C . when the contacts had become badly burned. The last 5,000 operations were made while the switch casing was open and surrounded by the most explosive mixture of gas and air. The gas was not ignited in any test.

Since no ignition occurred during the last 5,000 operations it is probable that none would have occurred had gas been present during the 70,000 previous operations, and hence the test was equivalent to 75,000 operations in explosive gas.

Table 3 shows that during the test the oil decreased 9.8 per cent in weight. This was due first to the escape of oil vapors through the openings designed to be completely filled by the leads entering the switch, but not so filled in this test; and second to the unavoidable loss of oil incident to the removal of the burned contact brushes and the substitution of new ones.

DISCUSSION OF RESULTS OF TEST.

The remarks on the results of test of switch OP1 (p. 23) apply also to switch OP4.

REMARKS ON SWITCH DESIGN.

The design and construction of the switch seems to be sufficiently substantial for mine service. The casing is so designed that leakage of oil is practically impossible. If the switch is to be used with any but lead-covered conductors the openings for the admission of such conductors to the casing will have to be of a form different from that used in the switch that was tested.

REMARKS ON THE GENERAL DESIGN OF AN ELECTRIC MINE SWITCH.

The purpose for which a switch is to be used will of course influence its design. In general, a mine switch is subjected to more severe service and to more abuse than a switch that is used above ground. Therefore a mine switch should be constructed more substantially than a switch for ordinary service. The voltage requirements of mine switches are not severe at present, although as the use of alternating current becomes more extensive higher voltages will no doubt be used underground. However, in places where there is danger of gas ignition a voltage of 440 for alternating current and 650 for direct current will probably never be exceeded. The current requirements are not unusual. The majority of mine switches are nonautomatic, fuses being used to open the circuits on overload.

Although often used merely as disconnecting switches, all switches for mine service should be capable of opening under at least twice their rated current load without blowing the fuse or damaging the connections.

There may be two classes of safety mine switches—those designed to be permanently connected into circuit and those so designed that the leads connecting the switch with its load are readily detachable. The latter class requires an interlocking connection between the detachable leads and the blades of the switch so that the circuit can not be opened by the removal of the detachable leads. The classification of safety mine switches has already been discussed in pages 6 and 7.

PERMISSIBLE SWITCHES FOR USE IN GASEOUS MINES.

As a result of the preliminary tests reported in the foregoing pages the bureau has decided to undertake tests to establish a list of permissible electric switches for use in gaseous mines.

The following is a statement of the character of the tests, the conditions under which they will be made, and the requirements for approval.

DEFINITIONS OF TERMS USED.

Permissible.—The Bureau of Mines considers a switch permissible if it is similar in all respects to the sample switch that passed certain tests made by the bureau, and if it is set up and used in accordance with the conditions prescribed by the bureau.

Permissible switches may be either of the oil type or of the explosion-proof type. Switches of either type may belong to the class having detachable leads (class D) or the class having permanently connected leads (class P).

Types.—The Bureau of Mines has applied the term “explosion-proof” to switches so constructed as to prevent the ignition of mine gas surrounding the switch by any sparks, flashes, or explosions of gas that may occur within the switch casing.

Oil-type switches are those that have their contacts immersed in oil for the purpose of confining the flash that takes place when the switch is opened under load.

REQUIREMENTS FOR APPROVAL.

IDENTIFICATION OF SWITCHES.

Before the Bureau of Mines approves any switch as permissible there shall be on file with the bureau the following data to be used for the identification of the switch and to be mentioned in the published approval of the switch:

1. The voltage and current rating of the switch.
2. Dimension drawings that show clearly—(a) the size and general appearance of the switch casing; (b) the relative arrangement of parts within the switch casing; (c) for explosion-proof switches the size and details of the protective devices and their relative arrangement on the switch casing; (d) for oil switches the trade name of the oil that should be used in connection with the switch; (e) any other drawings necessary to identify or explain any feature that is to be considered in the approval of the switch.

DESIGN AND CONSTRUCTION.

The design and construction of permissible mine switches must be especially substantial. This requirement shall be applied consistently to all the details of the switches as well as to their principal parts in order to give assurance that under the severe conditions of mining service the explosion-proof qualities of the switches will remain unimpaired.

The protective devices used with permissible explosion-proof switches must not only be capable of preventing the passage of flames from the interior to the exterior of the switch casing, but such devices must also possess sufficient mechanical strength to prevent the accidental impairment of their usefulness. If there are movable parts in connection with such devices, such parts must be so designed that there can be no interference with their movement. All joints in the casing of an explosion-proof switch must be metal-to-metal joints with broad faces. All openings in the casing of an explosion-proof switch other than those provided with protective devices by the manufacturers must be tightly closed. It is desirable that such openings be as few as possible. There must be no exposed terminals or contacts outside the switch casing. The leads connecting the switch with the power supply must enter the switch casing through gas-tight bushings of approved design and be provided with lugs for making permanent connections within such casings. If there are glass-covered openings in the casing of a switch, the glass must be protected by a metal cover or covers that close automatically unless held open. Class P explosion-proof switches must have the covers or doors of the switch casing so interlocked with the switch mechanism that the casing can not be opened when the switch is closed, nor can the switch be operated while the casing is open. Class D explosion-proof switches must be equipped like class P switches, and in addition have their detachable leads so interlocked with the switch mechanism that the leads can not be removed while the switch is closed.

Oil-type switches must be so designed and constructed as to reduce to a minimum the possibility of oil leaking from the switch casings. A practically air-tight casing is recommended. The switch contacts

must be well submerged in oil. All leads must leave the casing at points above the designated oil level. Class D oil switches must have their leads interlocked with the switch mechanism in the same manner as is prescribed for Class D explosion-proof switches.

CHARACTER OF TESTS.

TESTS OF EXPLOSION-PROOF SWITCHES.

In testing an explosion-proof switch for permissibility the switch casing will be filled and surrounded with the most explosive mixture of Pittsburgh natural gas and air. The mixture within the casing will then be ignited by means of a spark plug, by a flash from the switch contacts, or by any other means that simulates the conditions of actual practice. Similar tests will also be made with greater and with less proportions of gas in the explosive mixture and with coal dust sifted into the switch casing or into the protective devices. Tests will also be made to determine the point of ignition that gives the greatest pressure, and tests will be made by igniting from such a point. Not less than 50 tests of all kinds shall be made and more than that number may be made if, in the opinion of engineers of the bureau, more tests are necessary to prove the permissibility of the switch. In order to pass these tests, a switch must in none of them cause an ignition of the gas surrounding the switch or the discharge of flames from any part of the switch casing.

A switch will not be regarded as permissible, although it may have passed the tests just described, if used (*a*) without the caution plate described on page 33 or (*b*) with openings in the switch casing other than those openings provided with protective devices by the manufacturer.

EXPLOSION-PROOF FUSE CASINGS.

Only inclosed fuses should be used in connection with explosion-proof or oil switches. The fuses should be inclosed in explosion-proof casings or immersed in oil. The former practice is recommended because it renders the fuses easier of access when replacements are necessary.

If fuses are inclosed in explosion-proof casings, such casings will be tested in the same manner as switch casings of similar design. If fuses are submerged in oil, the investigation of this part of the equipment will consist of a thorough examination of the details of design and construction.

TESTS OF OIL-TYPE SWITCHES.

In testing an oil-type switch for permissibility the switch will be set up in an inclosure filled with the most explosive mixture of natural gas and air. The contacts of the switch will be covered with

oil to only 25 per cent of the depth designated by the manufacturer. Under these conditions 50 tests will be made by opening the switch under rated conditions of current and voltage. Direct current will be used in all tests. In order that a switch may successfully pass these tests its operation shall in none of them ignite the gas surrounding the switch. The mechanical design and construction of the switch will be considered in its approval.

Even if a switch has passed the tests just described it will not be considered as permissible if used without the caution plate described below.

CAUTION AND APPROVAL PLATES.

As part of the protection of a permissible switch the manufacturers shall be required to attach to an explosion-proof switch a metal plate inscribed as follows:

CAUTION.

The permissibility of this switch depends upon the absence of any openings in the casing other than those provided with protective devices by the manufacturer.

The casing should be frequently inspected for improper openings.

And to an oil-type switch a metal plate inscribed as follows:

CAUTION.

The permissibility of this switch depends upon the presence of the proper quantity of ———— oil in the switch casing.

The oil level should be carefully maintained at the point designated by the manufacturer.

The manufacturer shall be permitted to attach to the casing of an explosion-proof switch a plate inscribed as follows:

PERMISSIBLE EXPLOSION-PROOF SWITCH For use with permanent connections (or for use with detachable leads). Approval No. ———. U. S. BUREAU OF MINES.
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And to the casing of an oil-type switch a plate inscribed as follows:

PERMISSIBLE OIL SWITCH . For use with permanent connections (or for use with detachable leads). Approval No. ———. U. S. BUREAU OF MINES.
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The size, material, and design of both caution and approval plates shall meet with the approval of the bureau.

The caution and statement of approval could be combined upon a single plate, a suggested form for which is shown.

**PERMISSIBLE
EXPLOSION-PROOF SWITCH**

FOR USE WITH DETACHABLE LEADS

**APPROVAL No. _____
U. S. BUREAU OF MINES**

CAUTION.

The permissibility of this switch depends upon the presence in the switch casing of the proper quantity of _____ oil.

The oil level should be carefully maintained at the point designated by the manufacturer.

NOTIFICATION OF MANUFACTURER.

As soon as the engineers of the bureau are satisfied that a switch is permissible for use in places where gas may occasionally be present in such proportions as to form an explosive mixture, the manufacturer of the switch shall be notified to that effect. As soon as a manufacturer is formally notified that his switch has passed the tests prescribed by the bureau he shall be free to advertise such switch as permissible and may attach approval plates to such switches.

SCOPE OF APPROVAL.

The approval of any switch by the bureau shall be construed as applying to all switches of that specific type, class, form, and rating made by the same manufacturer and protected in the same manner, but to no other switches.

Manufacturers shall, before claiming approval by the bureau for any modification of any approved switch, submit to the bureau drawings that shall show the extent and nature of such modifications in order that the bureau may decide whether or not it will be necessary to test the remodeled switch before approving it. Each approval of a permissible switch will be given a serial number. Approvals of modified forms of a previously approved switch will bear the same number as the original approval with the addition of the letters A, B, C, etc.

WITHDRAWAL OF APPROVAL.

The bureau reserves the right to rescind for cause at any time any approval granted under the conditions herein set forth.

PRECAUTIONS.

It is obviously futile to protect the switch and neglect to safeguard any spark-producing accessory apparatus. It is equally unavailing to protect all of the apparatus if, within the limits made dangerous by the presence of gas, there are used in connection with the electrical equipment uninsulated wires or wires not properly connected with suitable insulators.

PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

The following Bureau of Mines publications may be obtained free by applying to the Director Bureau of Mines, Washington, D. C.

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls., 4 figs.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 42. Apparatus for the analysis of mine gases, by G. A. Burrell. 1913. — pp., — pls.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls., 4 figs.

BULLETIN 45. Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania, by N. H. Darton. 1913. 33 pp., 8 pls., 5 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls., 7 figs.

BULLETIN 50. A laboratory study of the inflammability of coal dust, by J. C. W. Frazer, E. J. Hoffman, and L. A. Scholl, jr. 1913. 60 pp., 95 figs.

BULLETIN 51. The analysis of black powder and dynamite, by W. O. Snelling and C. G. Storm. 1913. 80 pp., 5 pls., 5 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 53. Mining and treatment of feldspar and kaolin in the southern Appalachian region, by A. S. Watts. 1913. 171 pp., 16 pls., 12 figs.

BULLETIN 56. First series of coal-dust tests in the experimental mine near Bruceton, Pa., by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 59. Investigations of detonators and electric detonators, by Clarence Hall and S. P. Howell. 1913. 79 pp., 10 pls., 5 figs.

BULLETIN 62. Record of the national mine-rescue and first-aid conference, Pittsburgh, Pa., September 23, 25, 1912, by H. M. Wilson. 1913. 74 pp.

BULLETIN 65. Oil and gas wells through workable coal beds; papers and discussions, by G. S. Rice, O. P. Hood, and others. 1913. 101 pp., 1 pl., 11 figs.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigation of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

- TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp., 11 figs.
- TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl., 5 figs.
- TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.
- TECHNICAL PAPER 21. The prevention of mine explosions; report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.
- TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.
- TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp., 1 fig.
- TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.
- TECHNICAL PAPER 29. Training with mine-rescue breathing apparatus, by J. W. Paul. 1912. 16 pp.
- TECHNICAL PAPER 30. Mine-accident prevention at Lake Superior iron mines, by D. E. Woodbridge. 1913. 38 pp., 8 figs.
- TECHNICAL PAPER 31. Apparatus for the exact analysis of flue gas, by G. A. Burrell and F. M. Seibert. 1913. 12 pp., 1 fig.
- TECHNICAL PAPER 33. Sanitation at mining villages in the Birmingham district, Ala., by D. E. Woodbridge. 1913. 27 pp., 1 pl., 9 figs.
- TECHNICAL PAPER 40. Metal-mine accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 54 pp.
- TECHNICAL PAPER 44. Safety electric switches for mines, by H. H. Clark. 1913. 8 pp.
- TECHNICAL PAPER 46. Quarry accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 32 pp.
- TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 13 pp.
- TECHNICAL PAPER 48. Coal-mine accidents in the United States, 1896-1912, with monthly statistics for 1912, compiled by F. W. Horton. 1913. 74 pp., 10 figs.
- TECHNICAL PAPER 52. Permissible explosives tested prior to March 1, 1913, by Clarence Hall. 1913. 11 pp.
- MINERS' CIRCULAR 3. Coal-dust explosives, by G. S. Rice. 1911. 22 pp.
- MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp., 5 figs.
- MINERS' CIRCULAR 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.
- MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.
- MINERS' CIRCULAR 7. The use and misuse of explosives in coal mining, by J. J. Rutledge. 1913. 52 pp., 8 figs.
- MINERS' CIRCULAR 8. First-aid instructions for miners, by M. W. Glasgow, W. A. Raudenbush, and C. O. Roberts. 1913. 66 pp., 46 figs.
- MINERS' CIRCULAR 9. Accidents from falls of roofs and coal, by G. S. Rice. 1912. 16 pp.
- MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.
- MINERS' CIRCULAR 11. Accidents from mine cars and locomotives, by L. M. Jones. 1912. 16 pp.
- MINERS' CIRCULAR 12. The use and care of miners' safety lamps, by J. W. Paul. 1913. 16 pp., 4 figs.

